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Investigation of a Micromachined Electric Field Mill Using Dielectric Shutter

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Abstract

This paper investigates a new type of micromachined electric field mill (MEFM) fabricated using a silicon dielectric shutter. The performance of the MEFM is investigated as a function of the dimensional parameters for shutter perforation repetition period, width of perforations and electrodes, shutter thickness, and the gap between shutter and electrodes. Optimum shutter design is found and presented. Furthermore, performance is compared to that of a standard MEFM with an electrically grounded shutter. It is found that the dielectric silicon shutter MEFM has superior performance.

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1. Introduction

Electric field measurement is employed in various industries, such as power systems [1,2], electrostatic detection [3], and atmospheric science [4]. While ac electric field measurement is comparatively easy, dc electric field measurement is complicated because of no cyclic variation with respect to time. A few different technologies are employed for dc field sensing, such as force deflection sensor [5], the electro-optic meter [6], and the field mill [7]. The working principle of a field mill is that, by repeated chopping of the incident field using an electrically grounded shutter, an alternating field whose amplitude is proportional to the incident dc field is generated. The field strength of this alternating field can then be measured with the sensing electrodes by the amplitude of the induced current.

Based on the concept of the macroscopic field mill, a few micromachined electric field mill (MEFM) designs were investigated and fabricated [8-11]. Commonly a laterally vibrating perforated grounded shutter is used to periodically shield underlying sense electrodes from the incident dc field (Fig. 1). The MEFM from Horenstein et al.

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[8] consists of a single slit shutter and comb drive to actuate the shutter, while in the design of Chen et al. [9] employs a periodically perforated shutter actuated by thermal actuators. A resonant working shutter was used to improve MEFM performance by Wijeweera et al. [10], due to reduced drive signal to actuate the shutter. In [11], Gong et al. presented a study of the MEFM design for improved signal performance, as a function of geometry of the perforated grounded shutter and underlying electrodes.

An MEFM using an electrically floating shutter has not been investigated before. In this paper, we present this new concept for an MEFM, investigated for a dielectric silicon shutter, which is not connected to electric ground.

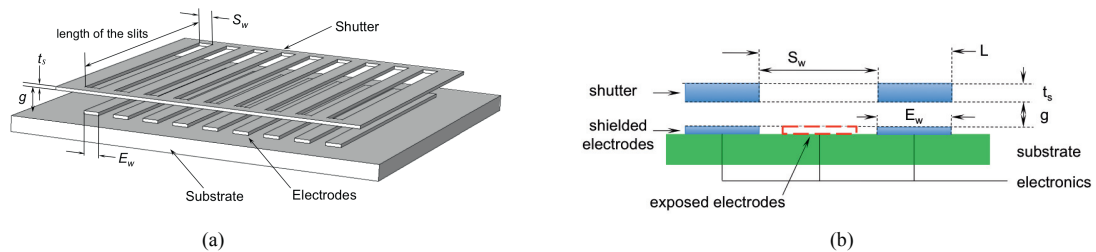


Fig. 1. (a) Schematic of a typical MEFM concept; (b) Cross-section of a MEFM.

2. Basic ideas and structure parameters

In Fig. 1, the parameters of S_w , t_s , E_w , and g are studied in simulation to determine their effects on the MEFM signal when measuring a dc electric field. All of four parameters are fully investigated using FEM simulations. The definitions and expected ranges of different MEFM design parameters are given in TABLE I.

Table 1. Definition of the MEFM design parameters and the expected range of each parameter.

Parameter	Definition
L	Shutter perforation repetition period
S_w	Width of slit in the shutter
E_w	Width of the electrodes
t_s	Thickness of the shutter
g	Gap between the shutter and electrodes

Among all these parameters, L corresponds to the total shutter displacement, while the other four are arbitrary with the condition that S_w and E_w should not be larger than L . The concept of the field mill is such that the sensing electrodes charge as one plate of a capacitor when exposed to an electric field. For the case of an ideal field mill with no fringing as the field passes the shutter perforation, the field measured by the sense electrode is:

$$E_{ex} = \frac{V_s}{d + t_s + g} \quad (1)$$

where d is the distance between the MEFM and an infinite plane voltage plate biased at V_s , see Fig. 2. While, for a shielded electrode under a dielectric shutter the field strength is:

$$E_{sh} = \frac{V_s}{d + g + \frac{t_s \cdot \epsilon_{rAir}}{\epsilon_{rSi}}} \quad (2)$$

where ϵ_{rAir} is the relative permittivity of air and ϵ_{rSi} is the relative permittivity of the silicon. Equation 2 shows that when the sense electrode is covered by the silicon shutter, E_{sh} is slightly larger than E_{ex} , due to the difference in the relatively permittivity of silicon being higher than air.

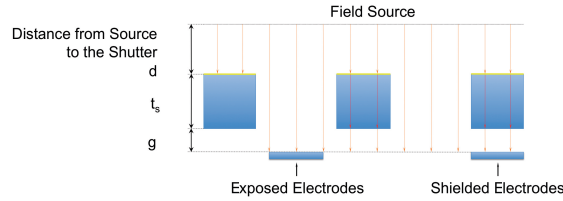


Fig. 2. Schematic view of the floating shutter MEFM design.

3. Results and analysis

The results of the simulations are presented in this section with the applied field strength equals 0.1 V/m. Fig. 3 (a) shows that the differential charge (Q_{diff}) measured by the sense electrodes from an incident dc field changes with shutter spacing from the electrodes, for a silicon dielectric shutter ($\epsilon_{rSi} = 11.67$). We see that the ratio of g/L , results in higher Q_{diff} (green) at low g/L ratios. On the other hand, Fig. 3 (b) shows the result of an electrically grounded shutter with the same dimensional parameters. Comparing Fig. 3 (a) and Fig. 3 (b), we see that although Q_{diff} in both figures increases as g/L decreases, few differences can be observed. First, in Fig. 3 (a), the shielded electrode (blue) has more induced charge than the exposed electrode and vice versa in Fig. 3 (b). Secondly, the induced charge on the exposed electrodes (red) in Fig. 3 (a) decreases along with a decreasing g/L unlike the one in Fig. 3 (b). Fig. 3 (c) shows the comparison of Q_{diff} in Fig. 3 (a) and Fig. 3 (b). We can see that Q_{diff} is higher for the dielectric silicon shutter than the electrically grounded shutter, for example ~ 3 times for $g/L = 0.2$ rising to over 5 times for $g/L = 0.1$.

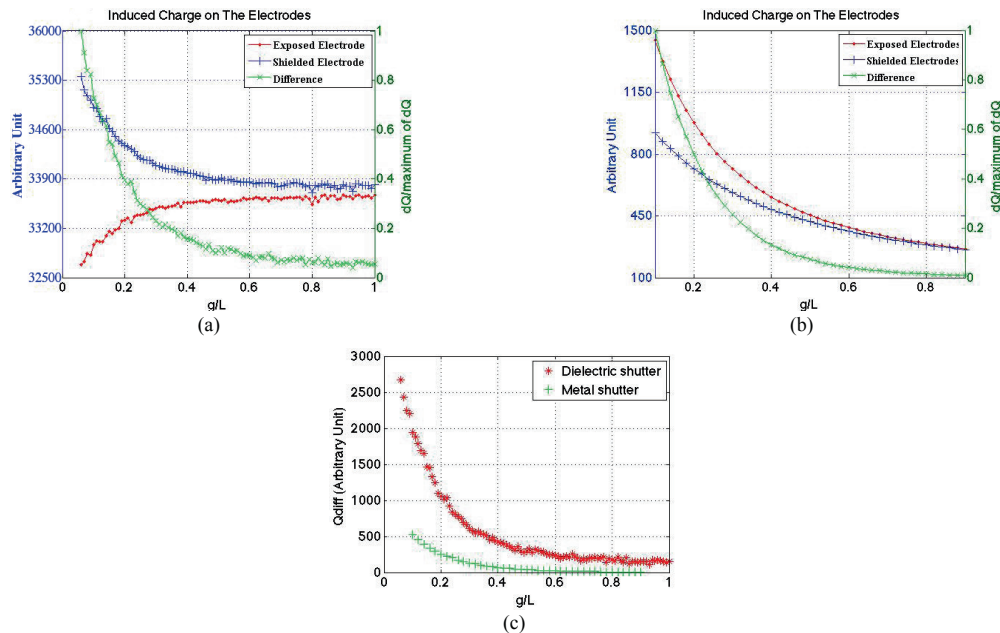


Fig. 3. (a) Induced charge on sensing electrodes for MEFM with a dielectric shutter; (b) Induced charge on sensing electrodes for MEFM with a grounded metal shutter; (c) Comparison between the dielectric shutter in (a) and the grounded shutter in (b).

Fig. 4 (a) demonstrates how Q_{diff} varies with t_s/L ratio (other parameters fixed at $S_w = 0.6L$, $E_w = 0.4L$, $g = 0.3L$). We can see that the amount of induced charge on the shielded electrodes increases with t_s while that on the exposed

electrodes decreases. We can see that Q_{diff} increases with increasing t_s , but this increment diminishes significantly for $t_s/L > 0.7$. This is a contrary to a conventional MEFM with an electrically grounded shutter, for which a thicker shutter leads to a smaller signal. Fig. 4 (b) shows how Q_{diff} varies with E_w and S_w . Over the axis of S_w/L , a peak can be observed around $S_w = 0.7L$ with $g = 0.1L$, though the peak shifts slightly with change of E_w and g . We can also see that Q_{diff} also generally increases with a decreasing E_w/L ratio. However, this begins to diminish for $E_w/L > 0.6$.

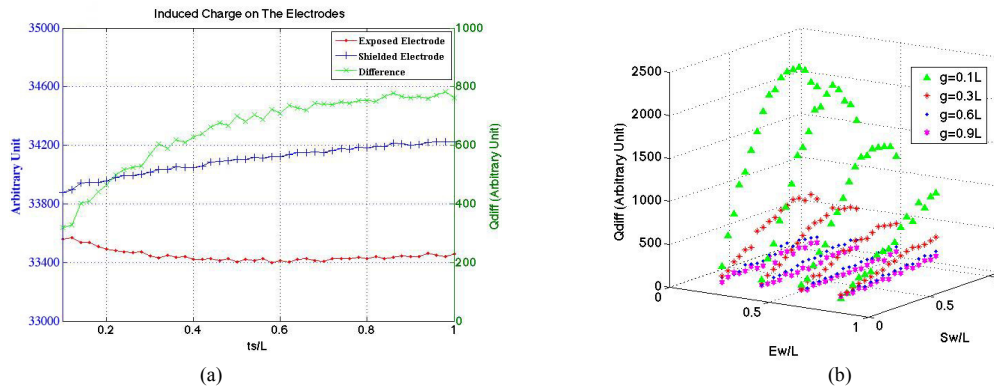


Fig. 4. (a) Q_{diff} (arbitrary units) as a function of t_s/L ; (b) Q_{diff} vs. S_w/L and E_w/L for different g .

4. Conclusion

The results of the simulation studies demonstrate the potential for an MEFM with dielectric shutter. Compared to the conventional MEFM with a grounded shutter, a silicon dielectric shutter can have a much better performance. Furthermore, according to simulation, a nearly optimal performance is obtaining for the case of $E_w/L = 0.6$, $S_w/L = 0.7$, $t_s/L = 0.7$, and $g/L = 0.1$.

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References

- [1] P. S. Maruvada, R.D. Dallaire, and R. Pedneault, Development of Field-Mill Instruments for Ground-Level and Above-Ground Electric Field Measurement Under HVDC Transmission Lines, *Trans. Power App. Syst.*, PAS-102 (1983) 738-744.
- [2] I. R. Vazquez, R. H. Corona, and G. M. Tena, Diagnostic of nonceramic insulators aged in a salt fog chamber by using electric field sensor, *Conference Record of the 2004 IEEE ISEI*, Indianapolis, USA, (2004) 471-474.
- [3] G. H. Vaillancourt, S. Carignan, and C. Jean, Experience with the Detection of Faulty Composite Insulators on High-Voltage Power Lines by the Electric Field Measurement Method, *IEEE Trans. on Power Delivery*, 13 (1998) 661-666.
- [4] R. Vishnu, V. A. Kumar, T.S. Sreekanth, V.N. S. Symon, S. M. Das, and G. M. Kumar, Formation of Thunderclouds in a Region of High Lightning Incidence, Inferred from AWS, Ceilometer and an Electric Field Mill, 7th *APL*, Chengdu, China, (2011) 135-139.
- [5] T. Chen, C. Shafai, MEM Electric Field Sensor using Force Deflection with Capacitance Interrogation, *IEEE PES*, (2013) 21-25.
- [6] K. Hidaka, Progress in Japan of space charge field measurement in gaseous dielectrics using a Pockels sensor, *IEEE EI Magazine*, 12 (1996) 17-28.
- [7] D. M. Taylor and P. E. Secker, *Industrial Electrostatics: Fundamentals and Measurements*, John Wiley & Sons Inc., New York, 1994.
- [8] M. N. Horenstein, P. R. Stone, A micro-aperture electrostatic field mill based on MEMS technology, *J. Electrostat.*, 51-52 (2001) 515-521.
- [9] X. Chen, C. Peng, H. Tao, C. Ye, Q. Bai, S. Chen, and S. Xia, Thermally driven micro-electrostatic fieldmeter, *SENSOR ACTUAT A-PHYS*, 132, Issue 2, (2006) 677-682.
- [10] G. Wijeweera, B. Bahreyni, C. Shafai, A. Rajapakse, and D.R. Swatek, Micromachined Electric Field Sensor to Measure ac and dc Fields in Power Systems, *IEEE Transactions on Power Delivery*, vol. 24, pp. 988-995, July 2009.
- [11] C. Gong, S. Xia, K. Deng, Q. Bai, S. Chen, Design and Simulation of Miniature Vibrating Electric Field Sensors, *Proc. IEEE Sensors*, 3 (2004) 1589-1592.